Missions for Cubesats

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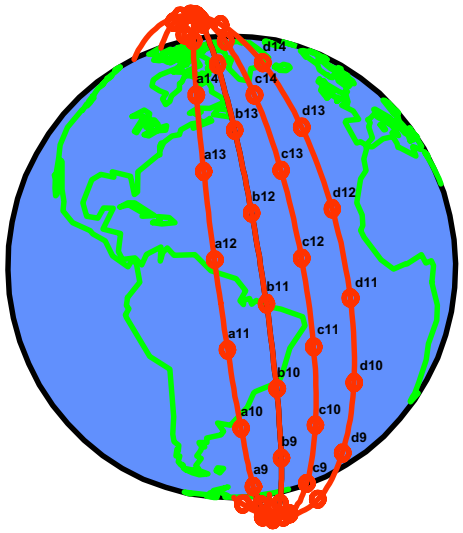
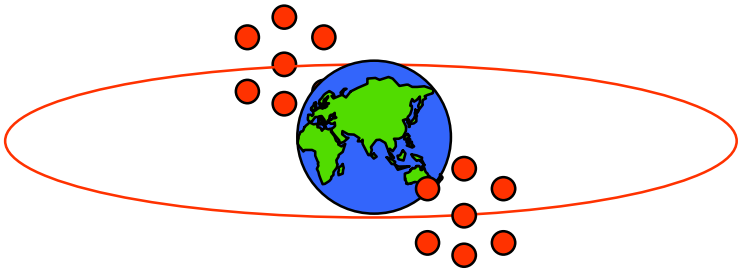
Nanosat (or CubeSat) Applications:

- **LEO Constellations**
  - Low-resolution Earth imaging
  - Communications relay
  - Space science measurements
- **Single Satellite Missions**
  - Co-orbital satellite assistant
  - Technology testbeds
- **Local Clusters**
  - RF interferometry



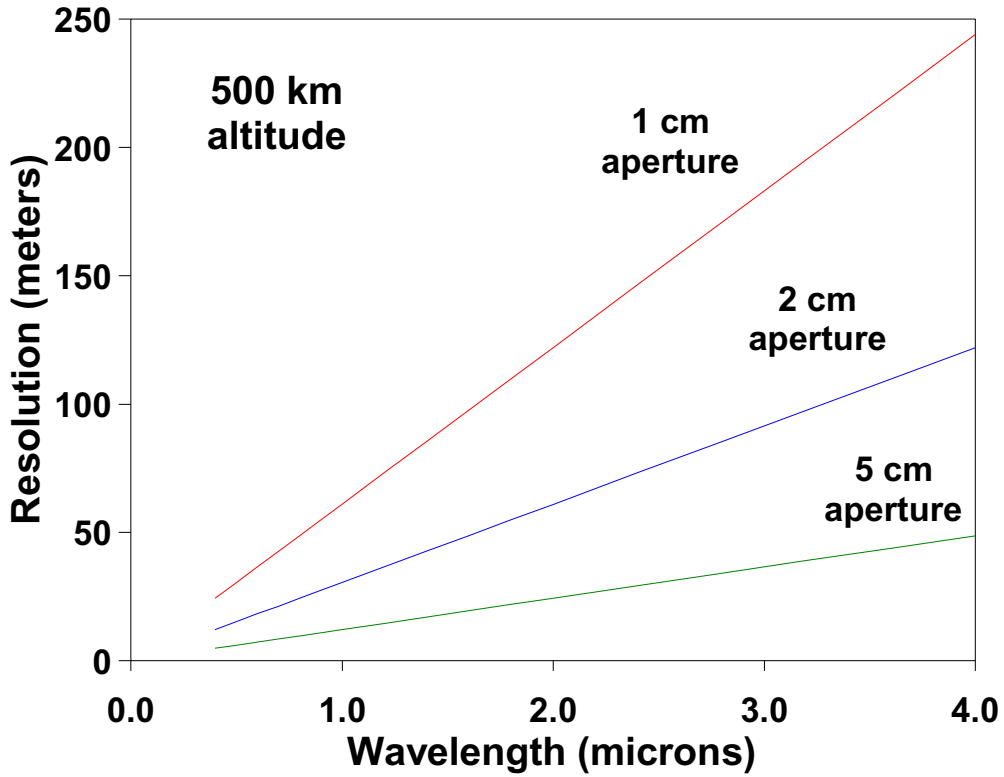


CubeSat Applications in LEO Constellations:

- **Earth observation at 10-to-1000 meter resolution**
  - Revisit times of 15 minutes possible
  - Several bands per satellite possible
  - Visible, near-IR, and mid-IR possible
  - NOAA and METEOR APT and HRPT replacement (VHF, L-band)
  - Launch on demand for emergency replacements
- **Communications**
  - Store-and-forward messaging
  - Remote sensor readout

What Can A Cubesat See?

Diffraction-Limited Optical Resolution:



Ground resolutions down to 10 meters in the visible are possible using 2" optics on a CubeSat.

Example Wavelength Bands for Earth Observation

Wavelength (microns)	Mission Applications
0.5 - 0.7	Visible features (clouds + snow, landmasses)
1.5 - 1.7	Cloud/snow differentiation
3.5 - 3.9	Fire detection, sea and land temperature
10.5 - 11.3	Cloud top temperatures

What Can A Cubesat See?

Linear imager, e.g., low Earth orbit weather satellites

500 pixels, 500-meter ground resolution, 250-km wide swath, 30^{o} FOV
64 kbit/s data rate @ 8-bits/pixel

2-D imager

Imager Density	Pixel Spacing	Imager Size	Ground Resolution	Field of View	Image Depth	Data per Image
640 x 480	7.4 μ	4.7 x 3.6 mm	50 m	3.7^{o} x 2.8^{o}	10 bits	3.1 Mbit
1280 x 1024	10 μ	12.8 x 10.2 mm	25 m	3.7^{o} x 2.9^{o}	12 bits	15.7 Mbit
1280 x 1024	10 μ	12.8 x 10.2 mm	10 m	1.5^{o} x 1.2^{o}	12 bits	15.7 Mbit

Example Microsat Multi-Spectral Image

- **TMSAT image**
  - Surrey Satellite microsat
  - Combined green, red, near IR
  - 1020 x 1020 pixels

San Fransisco at 98-meter resolution
http://www.sstl.co.uk/services/mn_san_fransisco.html

NOAA Weather Satellites: 4-km Resolution

NOAA-12: ~6:00 AM and 5:40 PM
NOAA-14: ~6:40 AM and 6:00 PM
NOAA-15: ~9:00 AM and 8:10 PM

AM passes: Southbound
PM passes: Northbound

Automatic picture transmission (APT) mode provides 4-km ground resolution in two wavelength ranges (visible and near IR) in a line-by-line format. The spacecraft transmits at 137.50 or 137.62 MHz **at 4 Watts using an FM carrier**. Modest ground antennas are required.

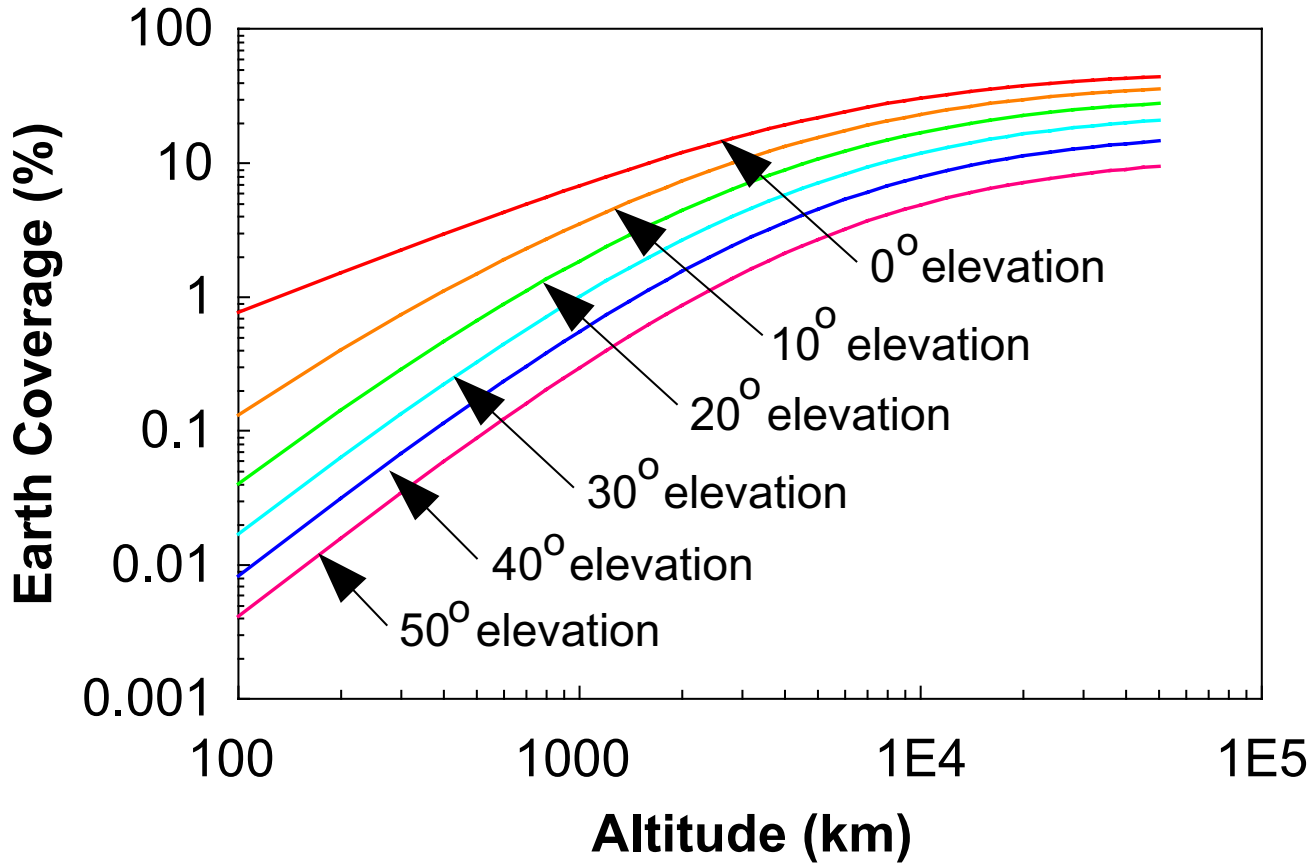
Sound card demodulator software: WXSAT

http://www.hffax.de/WX_Satellite/WXSat/wxsat.html

Additional information:

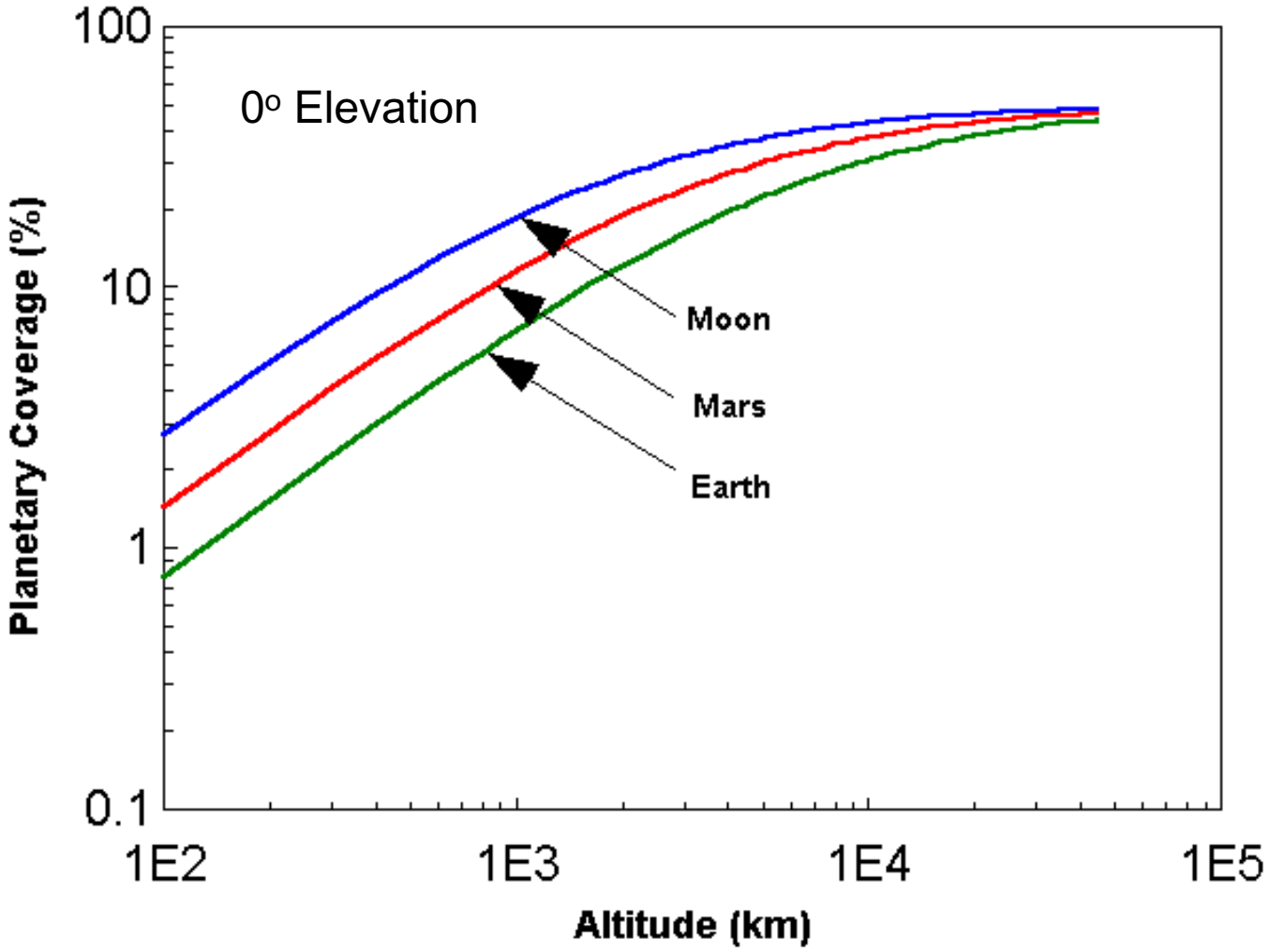
http://www.riglib.demon.co.uk/guide.htm

Geometric Earth Coverage for a Single Satellite



You need several hundred satellites in LEO (<1000 km altitude) to provide at least one satellite 40° above the horizon world-wide.

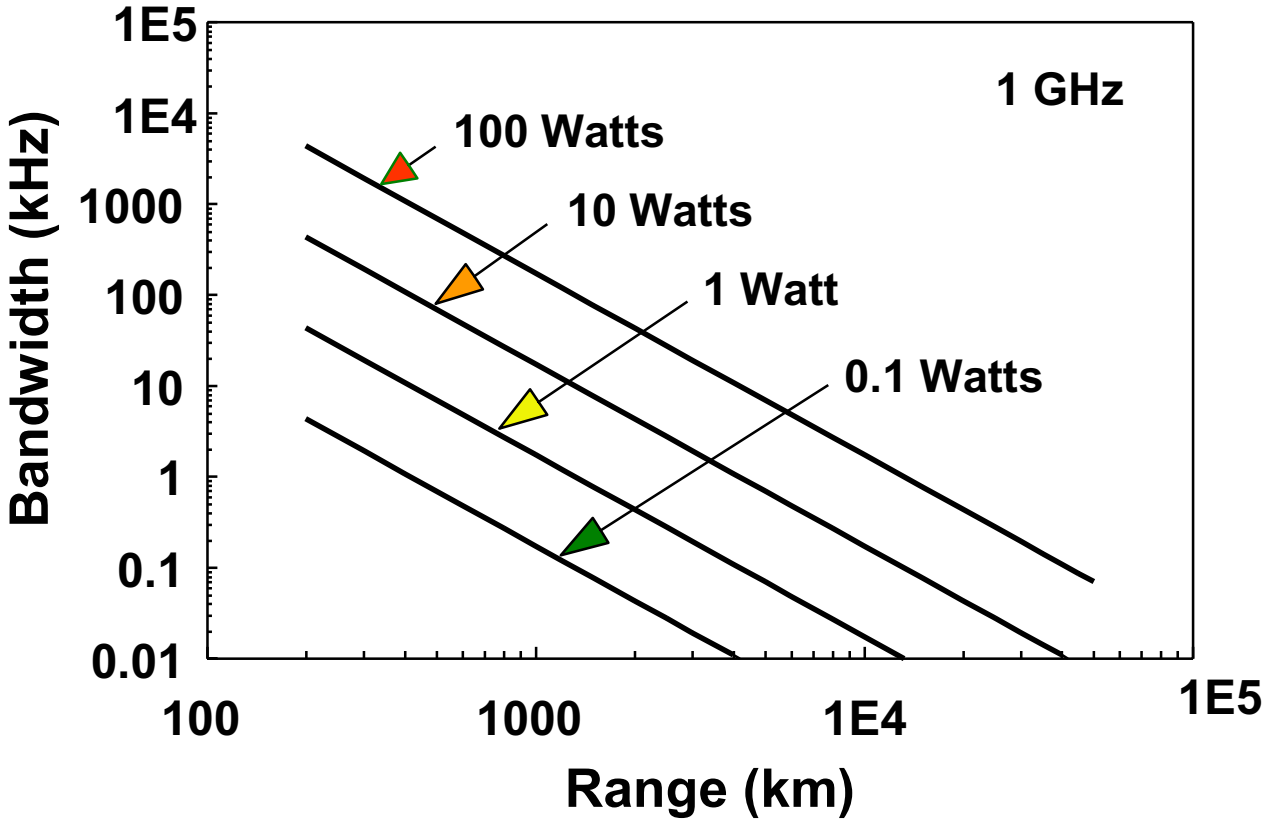
Geometric Planetary Coverage for a Single Satellite



Satellite Downlink Bandwidth

Transmit Gain: 0 dB
Receive Gain: 0 dB
Frequency: 1 GHz

Losses: 4 dB
Sky Temp.: 300 K
Preamp NF: 1.5 dB
Signal/Noise: 13.5 dB



Downlink Limitations

- **Typical micro/nanosat transmits 1-10 W at UHF**
  - Omnidirectional or low-gain antennas on satellite
  - Adequate for voice link using ~20” whip antenna on ground
  - Adequate for 9600 bps data using 2-to-3 foot long helix on ground
  - 1 Megabit/sec would require a 15’ dia. dish on ground
  - Bandwidth is usually a problem at UHF

- **Higher power transmitter not an option for CubeSats**
  - A CubeSat will operate with a ~1 Watt power budget
  - Low duty cycle operation at high power may be possible

- **Higher frequencies will force use of tracking antennas on ground**

Co-Orbital Satellite Assistants (COSAs)

- **Small spacecraft ejected from a platform**

- **Small spacecraft maneuvers about platform**
  - Imaging of platform
  - On-orbit calibration of sensors
  - Close-range mapping of rf/microwave/optical emissions
  - Low ΔV requirements (~1 meter/second)

- **COSAs have flown and are evolving**
  - Inspector (Mir)
  - Aercam (U.S. Space Shuttle Columbia)
  - MEMS Satellite Inspector (AFRL; under development)

Co-orbital Motion:

$$\text{Semimajoraxis} := 7078.16 \qquad \text{mu} := 398601.8 \qquad \text{omega} := \left(\frac{\text{mu}}{\text{Semimajoraxis}^3}\right)^{0.5} \qquad \text{omega} = 1.06 \cdot 10^{-3}$$

$$s0 := 0 \qquad r0 := 0 \qquad z0 := 0 \qquad dt := 180 \qquad vs0 := 0.003 \qquad vr0 := 0.0 \qquad vz0 := 0.0$$

$$i := 0 .. 33$$

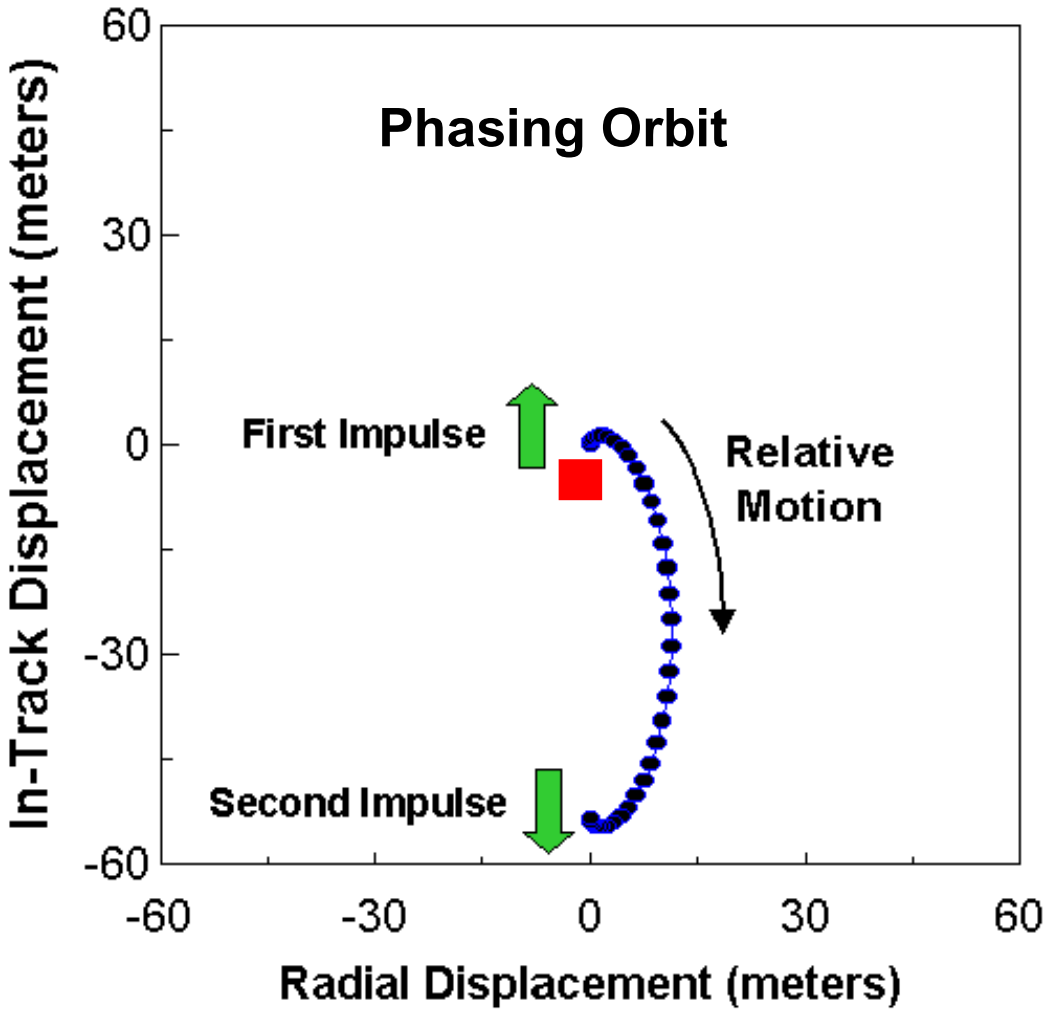
$$s_i := s0 + \left[2 \cdot vr0 \cdot \frac{(1 - \cos(\text{omega} \cdot i \cdot dt))}{\text{omega}}\right] + \left[\left[4 \cdot \frac{vs0}{\text{omega}} - (6 \cdot r0)\right] \cdot \sin(\text{omega} \cdot i \cdot dt)\right] + (((6 \cdot \text{omega} \cdot r0) - (3 \cdot vs0)) \cdot i \cdot dt)$$

$$r_i := (4 \cdot r0) - \left(2 \cdot \frac{vs0}{\text{omega}}\right) + \left[\left(2 \cdot \frac{vs0}{\text{omega}}\right) - (3 \cdot r0)\right] \cdot \cos(\text{omega} \cdot i \cdot dt) + \left(vr0 \cdot \frac{\sin(\text{omega} \cdot i \cdot dt)}{\text{omega}}\right)$$

$$z_i := \left(vz0 \cdot \frac{\sin(\text{omega} \cdot i \cdot dt)}{\text{omega}}\right) + (z0 \cdot \cos(\text{omega} \cdot i \cdot dt))$$

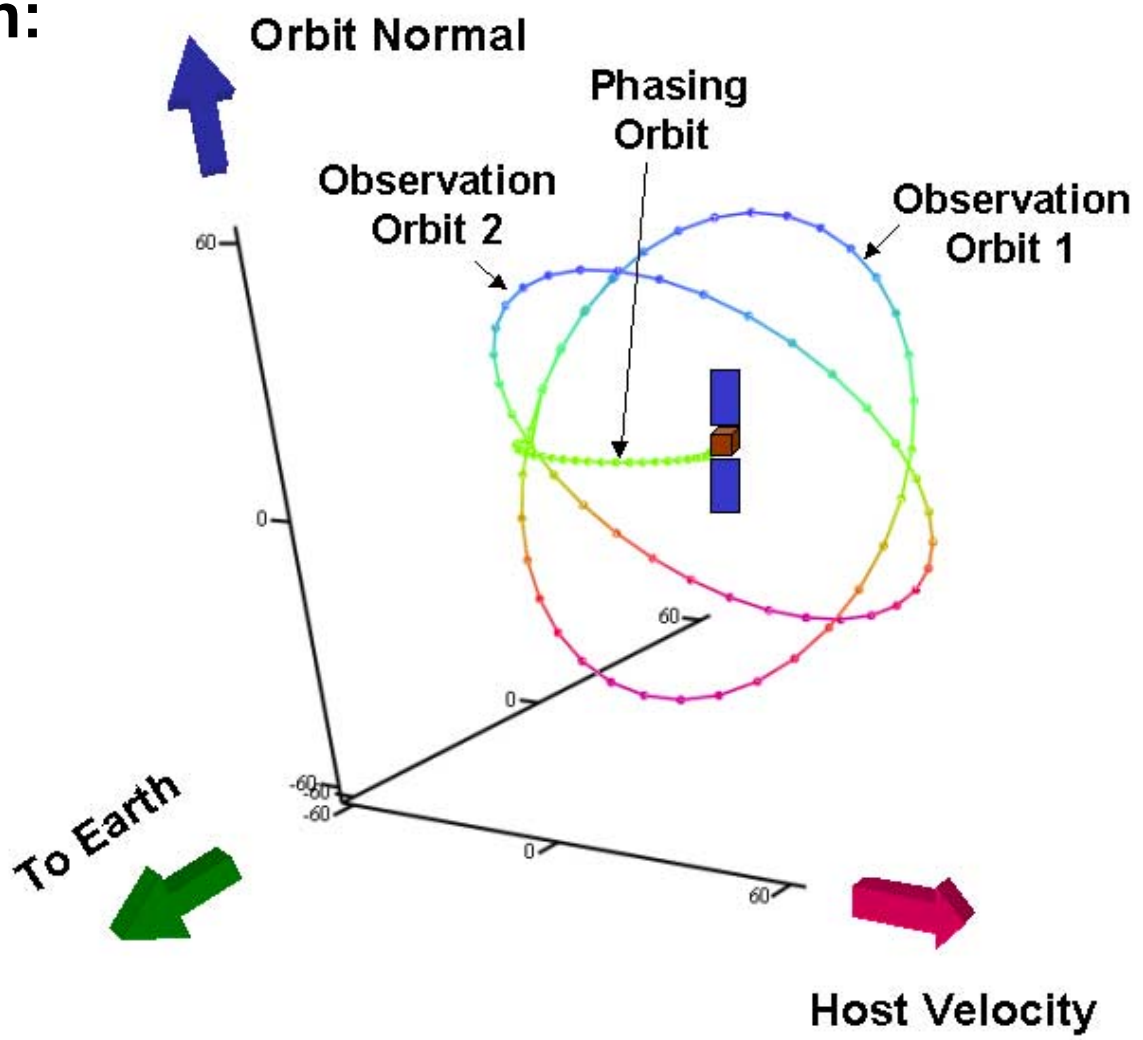
Co-orbital Motion:

- **Phasing orbit:**
  - 1st impulse: 3 mm/s
  - 2nd impulse: 3 mm/s
  - 99 minutes @ 700 km
  - mN thrust levels

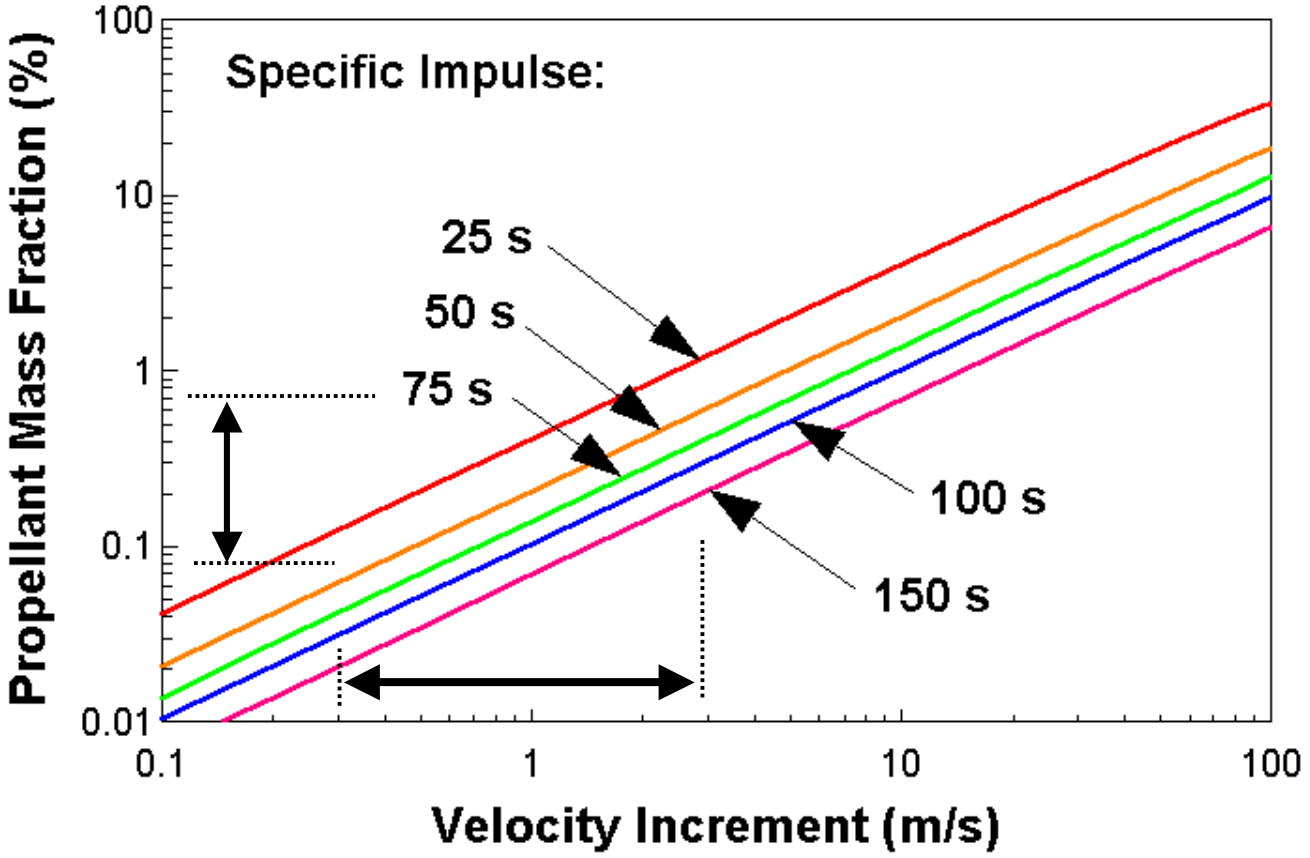


Co-orbital Motion:

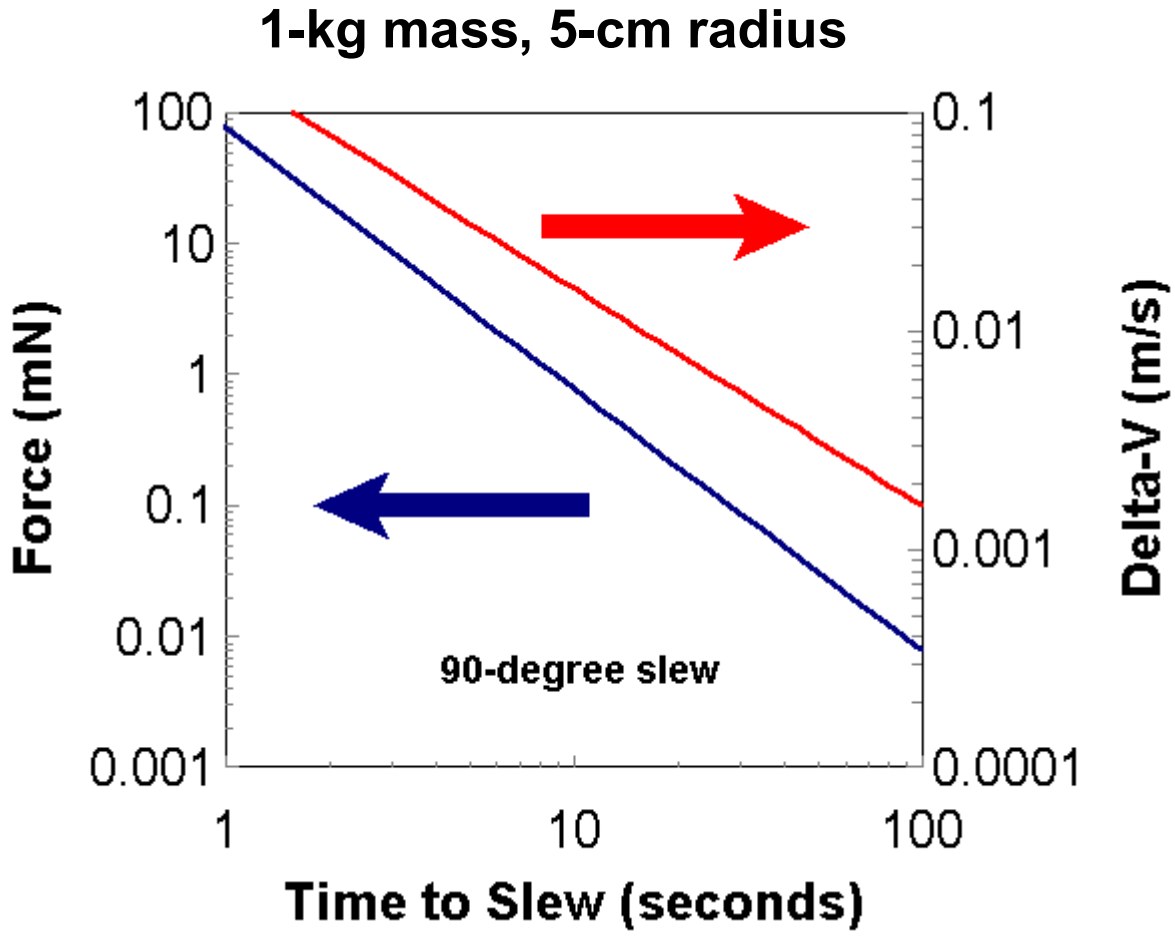
- **Observation orbits:**
  - Total: ~180 mm/s
  - mN thrust levels



Propellant Requirements: Less than 1%

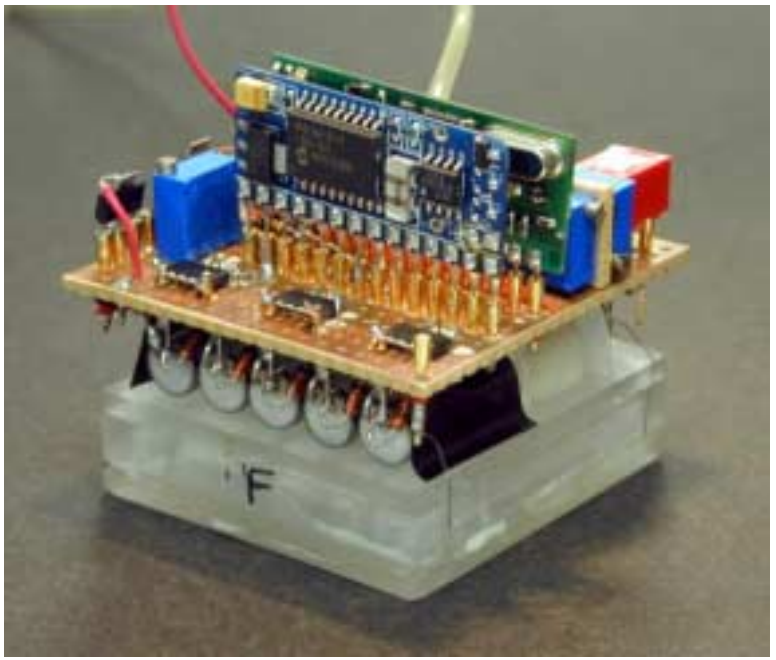


Attitude Control Requirements



2” Cube Cold Gas Thruster System:

- **6 Thrusters**
  - X-Y translation, Z-rotation
  - 5 valves
  - 10-mN thrusters
  - 10-ms minimum cycle
- **MEMS IMU**
  - Rate gyro (Analog Devices)
  - Accelerometers (Analog Dev.)
- **RF communications**
  - 9600 bps
  - Uplink/downlink



Summary:

- **CubeSats could perform Earth observation missions**
  - 10-1000 km ground resolution (visible)
- **CubeSats could perform the COSA mission**
  - Very low propulsion system requirements